# UNIVERSITI TEKNOLOGI MARA

# THREE DIMENSIONAL CUTTING FORCE AND TOOL DEFLECTION IN MICRO-END MILLING AISI D2

**NOOR ANIZA BINTI NORRDIN**

Thesis submitted in fulfillment
of the requirements for the degree of
**Master of Science**

**Faculty of Mechanical Engineering**

October 2016

# AUTHOR'S DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Teknologi MARA. It is original and is the results of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any degree or qualification.

I, hereby acknowledge that I have been supplied with the Academic Rules and Regulations for Post Graduate, Universiti Teknologi MARA, regulating the conduct of my study and research.

| | |
|---|---|
| Name of Student | : Noor Aniza Binti Norrdin |
| Student I.D. No. | : 2013823106 |
| Programme | : Master of Science (Mechanical Engineering) – EM750 |
| Faculty | : Mechanical Engineering |
| Thesis Title | : Three Dimensional Cutting Force and Tool Deflection in Micro-End Milling AISI D2 |
| Signature of Student | :...................................... |
| Date | : October 2016 |

# ABSTRACT

The miniaturization of products demand has been increasing since it compromises advantages such as high and better portability, accessibility and functionality in medicals, automotive, aerospace, electronics, environmental and energy industries. In order to produce such a high demand product, an advanced manufacturing processes that can produce small parts, cost effectively and high productivity is required. Micro-end milling is one of the most promising manufacturing processes that capable in manufacturing parts with complex features in micro-scale (< 1000 μm) due to its flexibility in processing a wide range of materials with a low setup cost. However, micro-end milling process has several challenges in precision manufacture of some products due to size effect, rapid tool wears, tool deflection and premature tool breakage. Moreover, the miniaturize products involve with tighter geometrical tolerance and high surface quality. These requirements and challenges make the selection of machining parameters for high performance micro-end milling more challenging. In this research, the development of a three-dimensional finite element model to simulate the micro-end milling operation of hardened AISI D2 cold work tool steel based on the commercial finite element package Abaqus/Explicit. The Johnson-Cook material constitutive model was employed to model the flow stress behavior of the workpiece. Coulomb's friction model was used to determine the frictional behavior of the tool-chip interface, Johnson-Cook damage model was used to realize chip separation and Arbitrary Lagrangian Eulerian (ALE) formulation has been adopted for the workpiece to reduce distortions during simulations. Based on the three-dimensional finite element model, cutting forces in three directions, $F_x$, $F_y$ and $F_z$ were predicted under different cutting parameters (cutting speed, $V_c$, feed rate, $f$, depth of cut, $d$) and cutting tool geometry (number of flutes; two, four, six, eight flutes and helix angle; 15° and 30°). Also, predictive models include outputs such as Von-Mises stress, as well as performance related measures such as tool wears and tool deflection. It has been found that cutting force increases as the feed rate, $f$ and depth of cut, $d$ increase and the cutting force decreases when high cutting speed, $V_c$ were used. Also, the use high number of flutes and helix angle in cutting tool was expected to improve the performance of the end mills, especially in terms of surface quality. Moreover, the larger cutting edge attained due to tool wear significantly increases the cutting forces, leading to tool deflection. Therefore, this research demonstrates the capabilities of micro-end milling in manufacturing micro-products of hardened AISI D2 cold work tool steel and an agreement of micro-milling force trends were achieved with the literature.

# TABLE OF CONTENTS

# CHAPTER ONE

# INTRODUCTION

## 1.1 RESEARCH BACKGROUND

Over the last few decades, the demand of miniaturized products and components has been increasing in medicals, automotive, aerospace, electronics, environmental and energy industries. Advanced machining processes are continually functioned a vital role in the field of producing these products and components with complex geometric features in micron level of accuracy. Keeping in mind that the miniaturized products and components are consist of micro- and meso-scale parts. A micro-machining is a process which is capable to manufacture parts with micro-scale (1-1000 μm) features while meso-machining process is capable to manufacture parts with meso-scale (1-10mm) features[1]. It is generally a scaled down versions of conventional and non-conventional macro-machining processes.

The micro-machining technology is well-known with the competence and gradually improved in precision machining, motivated to fabricate small products with reduced size and weight, higher surface quality and part accuracy as well as reasonable cost and better efficiency. Micro-milling process is one of the micro-machining processes that capable to produce a micro scale workpiece with higher accuracy. It has been applied in many industrial areas concerning to improve processes for small series of productions due to its advantage element of making more complex geometry in a wide variety of materials in comparison with other micro-machining methods. The mechanical modeling of micro-milling process interests many researchers to explore in this field and aim to define the principle for explaining the machining performances and results.

There is a point of limitation on how far the process can be scaled down. The dimensions of chip loads and tool geometry for micro-milling operations are different with macro-milling operations. It is normally in lower sizes which tend to offer difficulty in modeling and process control. Significant factors such as tool geometry and cutting parameters must be carefully measured in order to avoid premature wear and tool breakage. Normally the diameters of micro end mills are in the range of 25 μm–1.0 mm with 2–10 mm length of flutes [2]. Due to that, the cutting forces in